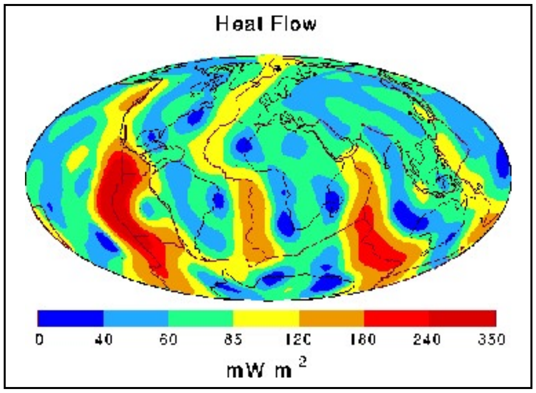
# The Hot Lunar Interior




Earth heat flow map (H. N. Pollack, S. J. Hurter, and J. R. Johnson, Reviews of Geophysics, Vol. 31, 1993.)

When large bodies form, their interiors are heated by a combination of radioactivity and the heat of formation from the infall of the rock. For planet-sized bodies, this heat can be generated and lost over billions of years. The end result will be that the core cools off and, if molten, it eventually solidifies. Measuring the surface temperature of a solid body, and the rate at which heat escapes its surface, provides clues to its internal heating and cooling rates.

**Problem 1** - Measuring the heat flow out of the lunar surface is a challenge because the monthly and annual changes of surface solar heating produce interference. Apollo 15 astronauts measured the heat flow from two bore holes that reached about 2-meters below the surface. When corrected for the monthly effects from the Sun, they detected a heat flow of about 20 milliWatts/meter$^2$. If the radius of the Moon is 1,737 kilometers, what is the total thermal power emitted by the entire Moon in billions of watts?

**Problem 2** - A future lunar colony covers a square surface that is 100 meters x 100 meters. What is the total thermal power available to this colony by 'harvesting' the lunar heat flow?

**Problem 3** - The relationship between power, L, surface radius, R, and surface temperature, T, is given by $L = 4 \pi R^2 \sigma T^4$ where $\sigma$ = the Stefan-Boltzman constant and has a value of $5.67\times10^{-8}$ W/m$^2$ / K$^4$ , and where T is in Kelvin degrees, L is in watts, and R is in meters. Suppose the Moon's interior was heated by a source with a radius of 400 kilometers at the lunar core, what would the temperature of this core region have to be to generate the observed thermal wattage at the surface?

**Problem 4** - The lunar regolith and crust is a very good insulator! Through various studies, the temperature of the Moon is actually believed to be near 1,200 K within 400 km of the center. A) Using the formula for L in Problem 3, how much power is absorbed by the lunar rock overlaying the core? B) From you answer to (A), how many joules are absorbed by each cubic centimeter of overlaying lunar rock each second (joules/cm$^3$)? C) Basalt begins to soften when in absorbs over 1 million Joules/cm$^3$. Is the lunar surface in danger of melting from the heat flow within?

# Answer Key

**Problem 1** - The surface area of a sphere is $4\pi R^2$, so the surface area of the moon is $4 \times 3.14 \times (1.737 \times 10^6)^2 = 3.8 \times 10^{18}\ m^2$ .The total power, in watts, is then 0.020 watts/$m^2 \times 3.8 \times 10^{18}\ m^2 = 7.6 \times 10^{11}$ watts or 760 billion watts.

**Problem 2** - The surface area is 100 x 100 = 10,000 $m^2$, and with a heat flow of 0.020 milliwatts/$m^2$, the total thermal power is 200 watts.

**Problem 3** - The total thermal power, L = $7.6 \times 10^{11}$ watts, and R = 400 km = 4.0 x 105 meters, so that $7.6 \times 10^{11} = 4 \times (3.14) \times (4.0 \times 10^5)^2 \times 5.67{\times}10^{-8}\ T^4$
Then $7.6 \times 10^{11} = 1.1 \times 10^5\ T^4$. Solving for T we get T = 51 K.

**Problem 4** - A) The power emitted by the 400 km, 1,200 K core region is given by

$$L = 4 \pi R^2 \sigma T^4$$

which equals $L = 4 \times (3.14) \times (4.0 \times 10^5)^2 \times 5.67{\times}10^{-8}\ (1200)^4 = 2.4 \times 10^{17}$ watts. Since from the answer to Problem 1 the amount that makes it to the surface is only $7.6 \times 10^{11}$ watts, that leaves essentially all of the $2.4 \times 10^{17}$ watts to be absorbed by the overlaying rock mantle.

B) The volume of overlaying rock is the total volume of the moon (radius 1,737 km) minus the volume of the 400-km lunar core. The difference in these two spherical regions is: $4/3\ \pi\ ( (1.737 \times 10^6)^3 - (4.0 \times 10^5)^3) = 4/3 \times 3.14 \times (5.18 \times 10^{18}) = 2.2 \times 10^{19}\ m^3$, or $2.2 \times 10^{25}\ cm^3$. Since 1 watt = 1 Joule/sec, then in 1 second the lunar thermal power from the 1,200 K core is $2.4 \times 10^{17}$ joules as calculated in (A). If this is evenly absorbed by the rock in the mantle, the average thermal heating energy per $cm^3$ is just $2.4 \times 10^{17}$ joules / $2.2 \times 10^{25}\ cm^3$. or $1.0 \times 10^{-6}$ joules/$cm^3$. (This is also equal to 10 ergs /$cm^3$)

C) No, because this amount of energy input is completely negligible in melting, or warming, rock material. Note: Basalt softens at 1,200 C = 1,500 K. A cubic centimeter of this rock has a surface area of 6 $cm^2$, so from $L = SA \times \sigma T^4$ we get $L = 6.0 \times 5.67{\times}10^{-8}\ (1500)^4 = 1.7 \times 10^6$ watts, which in 1 second amounts to $1.7 \times 10^6$ Joules / $cm^3$ - the energy needed to melt basalt.